Year: 2018

Can lung ultrasound be the first-line tool for evaluation of intraoperative Hypoxemia

Díaz-Gómez, José L ; Renew, J Ross ; Ratzlaff, Robert A ; Ramakrishna, Harish ; Via, Gabriele ; Torp, Klaus

DOI: https://doi.org/10.1213/ANE.0000000000002578

Originally published at:
Díaz-Gómez, José L; Renew, J Ross; Ratzlaff, Robert A; Ramakrishna, Harish; Via, Gabriele; Torp, Klaus (2018). Can lung ultrasound be the first-line tool for evaluation of intraoperative Hypoxemia. Anesthesia and Analgesia, 126(5):1769-1773.
DOI: https://doi.org/10.1213/ANE.0000000000002578

Can Lung Ultrasound Be the First-Line Tool for Evaluation of Intraoperative Hypoxemia?

José L. Díaz-Gómez, MD,*†‡ J. Ross Renew, MD,* Robert A. Ratzlaff, DO,*† Harish Ramakrishna, MD,§ Gabriele Via, MD,‖ and Klaus Torp, MD*

INTRAOPERATIVE LUNG ULTRASONOGRAPHY: IS IT FEASIBLE AND WORTHY?

Several diagnostic and monitoring applications of lung ultrasonography in surgical anesthesia (LUSA) have been described over the last decade.[1–3] The inherent qualities of LUSA (wide availability, lack of radiation, portability, and immediate interpretation) make it particularly attractive for the intraoperative setting, and some have proposed that LUSA be used in the intraoperative period.[4] In this Open Mind, we describe how lung ultrasonography may contribute to the clinical assessment of intraoperative hypoxemia and suggest how anesthesiologists might benefit from LUSA.

METHODOLOGICAL FRAMEWORK FOR THE APPLICATION OF INTRAOPERATIVE LUNG ULTRASONOGRAPHY

The current approach to intraoperative hypoxemia involves an assessment of technical factors such as gas mixture, mechanical ventilator function and settings, anesthesia machine and circuit issues, and patient factors derived from lung auscultation, chest radiography, and flexible bronchoscopy. We argue that integrating ultrasound into this clinical approach will improve diagnostic accuracy and time to recognition of the most common causes of intraoperative or perioperative hypoxemia. This lung ultrasonography-empowered approach to hypoxemia utilizes many of the same techniques as conventional approaches (Table 1) and adds distinct features related to ultrasound itself (Table 2).

From the Departments of *Anesthesiology and Perioperative Medicine, †Critical Care Medicine, and ‡Neurologic Surgery, Mayo Clinic, Jacksonville, Florida; §Division of Cardiovascular and Thoracic Anesthesiology, Mayo Clinic, Scottsdale, Arizona; and ‖Department of Anesthesia and Intensive Care, Fondazione IRCCS Policlinico San Matteo, Pavia, Italy.

Accepted for publication September 12, 2017.

Funding: None.

The authors declare no conflicts of interest.

Gabriele Via, MD, is currently affiliated with the Cardiac Anesthesia and Intensive Care, Cardiocentro Ticino, Lugano, Switzerland.

Reprints will not be available from the authors.

Address correspondence to José L. Díaz-Gómez, MD, Department of Critical Care Medicine, Mayo Clinic, 4500 San Pablo Rd, Jacksonville, FL 32224. Address e-mail to Diazgomez.jose@mayo.edu.

DOI: 10.1213/ANE.0000000000002578

LUNG ULTRASOUND-DRIVEN APPROACH TO INTRAOPERATIVE HYPOXEMIA: FROM PREANESTHESIA EVALUATION TO POSTANESTHESIA RECOVERY

Preoperative Period

LUSA is based on a well-validated collection of signs (Figure).[5] In addition, clinical context (preexisting hypoxemia, recent dyspnea, or acute change in oxygen saturation) is crucial for the application of LUSA. The most relevant preoperative diagnoses identifiable by LUSA include acute interstitial pulmonary edema (APE), pleural effusions, and lung consolidation. LUSA has a high (>90%) sensitivity for detecting the B-line pattern (>3 B lines in a longitudinal scan), which is the hallmark of APE in patients without preexisting end-stage lung disease. The B-line pattern can be seen on LUSA in either high-pressure (cardiogenic) or low-pressure (capillary leak) APE[6] and is the visual analog to crackles in lung auscultation. B lines, however, are much more sensitive than crackles or even arterial oxygen partial pressure for diagnosing APE. In patients with acute respiratory distress syndrome (ARDS), LUSA may reveal a nonhomogenous distribution of B lines in nongravity-dependent lung regions, irregular pleural lines, diminished lung sliding, and subpleural consolidations.[7] Furthermore, LUSA characterizes ARDS severity more accurately than do lung compliance and oxygenation index.[8,9] In patients with chronic lung disease, B lines are present at baseline, and sequential LUSAs finding fewer B lines after diuretic administration may clarify the diagnosis of APE.

Although the B-line pattern is the hallmark of APE, its presence is not pathognomonic as it may be seen in other conditions such as preexisting pulmonary fibrosis, pneumonia, and loss of aeration not reaching the magnitude of complete atelectasis. Hence, clinical context is important. Under optimal conditions, the diagnostic accuracy of LUSA for APE (95%) is higher than chest x-ray (72%) and auscultation (55%) in patients with ARDS.[10]

A preoperative moderate to large pleural effusion is another potential cause of early oxygen desaturation after anesthesia induction.[11] LUSA not only identifies such effusions but also provides semiquantitative data that can impact the decision to insert a thoracostomy tube or perform preoperative thoracentesis. By using Balik's simplified formula,[12] V = Sep × 20, clinicians can calculate the volume of pleural fluid in milliliters (V). Three measurements are taken and averaged with the ultrasound-phased array probe perpendicular to the thorax.[12]

Table 1. Techniques for Diagnosing Perioperative Hypoxemia That May Be Used in Both Conventional and Lung Ultrasonography Evaluations

	Intraoperative Patient Conditions	Intraoperative Equipment Factors
Preinduction Evaluation in Unplanned Anesthesia	**Evaluation of Intraoperative Hypoxemia (Spo_2 < 94%): Consider Hypoxia Until Otherwise Proven + Administer High Fio_2 (+Consider Hand Ventilation)**	
Clinical inspection, breathing pattern, chest excursions (RSB, bradypnea, hypoventilation) Auscultation Bronchospasm: wheezes Secretion accumulation: rhonchi ABG	Check $Etco_2$ (hypoventilation? low cardiac output? hyperthermia?) Auscultation Bronchospasm: wheezes Secretion accumulation: rhonchi ABG Assess skin for rash (allergic reaction) Check body temperature (increased oxygen consumption) Assess circulatory status (signs of low CO, hypotension)	Pulse oximetry probe on patient? Poor waveform factors (cold extremity, cautery, dyes, poor circulation to extremity, ie, Raynaud's phenomenon) Oxygen supply—pipeline pressures Circuit disconnection or obstruction ETT position, patency, and cuff Ventilator working? Peak airway pressures ABG

Abbreviations: ABG, arterial blood gas and acid–base status; CO, cardiac output; $Etco_2$, end-tidal carbon dioxide; ETT, endotracheal tube; Fio_2, fraction of inspired oxygen; RSB, rapid shallow breathing; Spo_2, arterial oxygen saturation; Vt, tidal volume.

Table 2. Distinctive Features Between Conventional and LUSA Approaches for Diagnosis of Perioperative Hypoxemia

Approach	Preinduction Evaluation in Unplanned Anesthesia	Intraoperative Hypoxemia: Patient Conditions
Conventional evaluation of intra operative/perioperative hypoxemia (Spo_2 < 94%)	Auscultation Pulmonary edema/fluid overload: bilateral diffuse crackles Pneumothorax, suspected large effusion: unilateral abolition of lung sounds Atelectasis/pleural effusion/atelectasis/pneumonia-reduced dorsal breath sounds Bronchospasm: wheezes Secretion accumulation: rhonchi Chest x-ray	Auscultation (as in "Preinduction Evaluation in Unplanned Anesthesia") consistent with: Esophageal intubation? Mainstem intubation? Bronchospasm? Secretions? Pneumothorax? Pulmonary edema/fluid overload? Atelectasis Chest x-ray
LUSA-empowered evaluation of intraoperative/perioperative hypoxemia (Spo_2 < 94%)	LUSA Pulmonary edema: bilateral diffuse, homogenous "B" pattern *Pneumothorax:* absent lung sliding, presence of "lung point," absent "B" pattern Pleural effusion: anechoic lung base-diaphragmatic interface Consolidation: heterogeneous hypoechoic visible lung/focal "B" pattern—(atelectasis or pneumonia) Impending major atelectasis: absent lung sliding, presence of "lung pulse" Derecruited dorsal areas: LUSA, dorsal "B pattern" Focus Signs of severe hypovolemia, severe LV or RV systolic dysfunction, cardiac tamponade physiology: low CO causing low $Svco_2$ Focus: PE—deep venous thrombosis?	LUSA (as in "Preinduction Evaluation in Unplanned Anesthesia") consistent with: Pulmonary edema Pneumothorax Pleural effusion Consolidation Impending major atelectasis/endobronchial intubation: absent lung sliding, presence of "lung pulse" Derecruited dorsal areas Aspiration, pneumonitis: unilateral or bilateral, heterogeneous "B" pattern Focus Signs of severe hypovolemia, severe LV or RV systolic dysfunction, cardiac tamponade physiology: low CO causing low $Svco_2$ Focus: PE—deep venous thrombosis?

Abbreviations: CO, cardiac output; DVT, deep venous thrombosis; FOCUS, focused cardiac ultrasound; LUSA, lung ultrasound in surgical anesthesia; PE, pulmonary embolism; $Svco_2$, central-venous oxygen saturation.

LUSA also permits bedside recognition of pneumonia and atelectasis, 2 potential causes of lung consolidation and hypoxia. The ultrasound appearance of lung consolidation in pneumonia is described as hyperechoic punctiform images with irregular boundaries, a liver tissue-like appearance termed lung hepatization, and multiple well-defined, irregularly spaced B lines originating from the pleural line. Furthermore, pneumonia can produce visible dynamic linear air bronchograms, an ultrasound finding pathognomonic for consolidation.[13] In contrast, atelectasis is characterized by fewer B lines, static air bronchograms, and a homogenous hyperechoic appearance.

Intraoperative Period

The intraoperative application of ultrasound is an emerging area of interest. A 2017 pilot study[14] found that LUSA may be used to track the degree of atelectasis during laparoscopic surgery and that LUSA findings correlate with changes in oxygenation. Specifically, the authors found that an ultrasound-derived aeration score correlated with oxygenation (Pao_2/Fio_2 ratio) changes.[14] Another 2014 investigation by Acosta et al[15] found good agreement between LUSA and magnetic resonance imaging assessments of atelectasis. In addition to evaluating atelectasis, dynamic visualization of

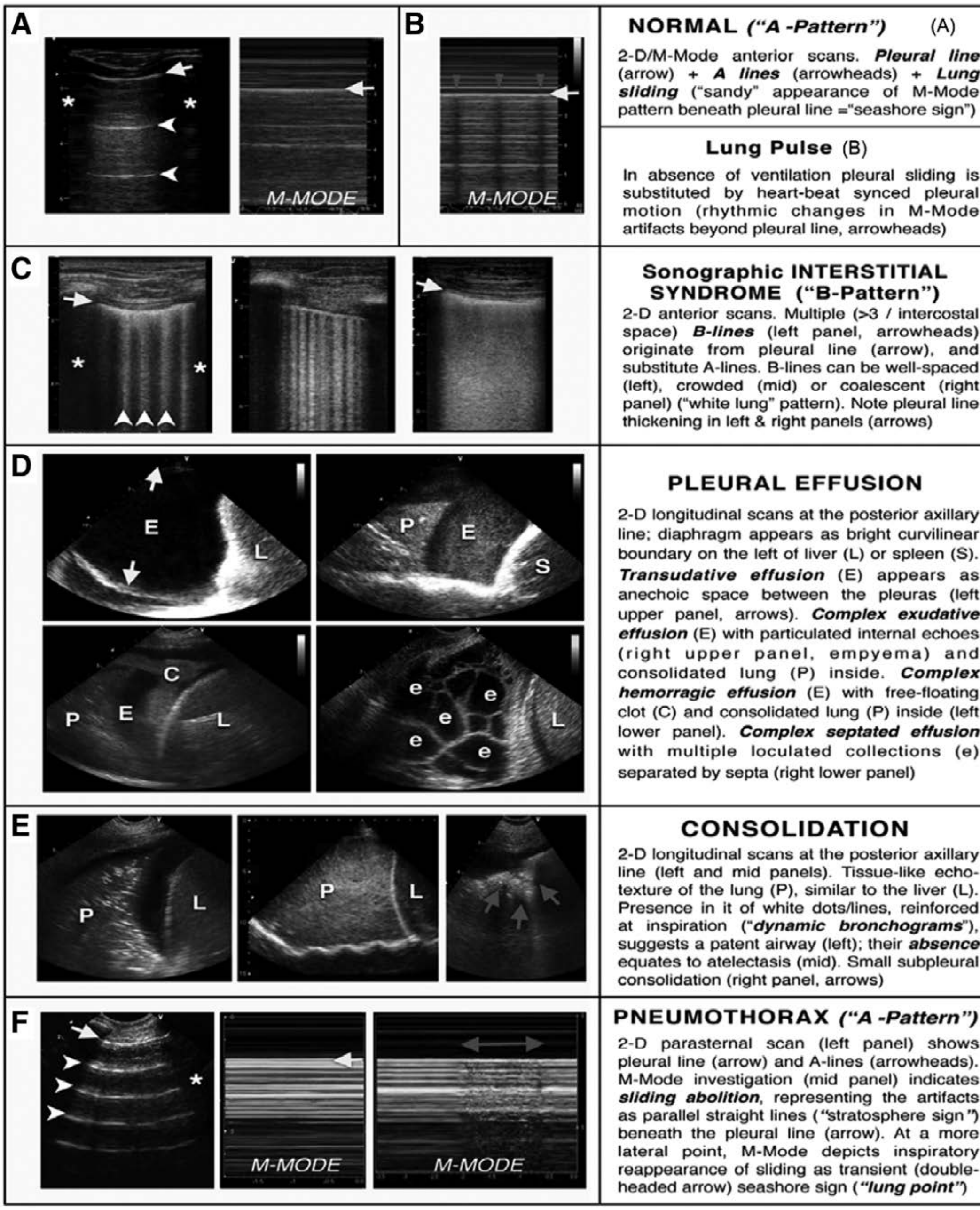

Figure. Synopsis of lung ultrasound semiotics. Main segmental patterns are illustrated (left column) and described in their distinctive features (right column). Normal pattern (A), sonographic interstitial syndrome (>3 B lines/intercostal space) (C), and pneumothorax (1F) are mutually exclusive artifact-based patterns. Pleural sliding (A) and lung pulse (B) are representations of visceral pleural motion (in a ventilated and a nonventilated lung area, respectively) and are here shown using M-mode imaging as having a different appearance of artifacts beyond the pleural line. M mode provides representation over time of reflected echoes from a single scanning line. Effusion (D) and consolidation (E) are image-based patterns. E indicates effusion; e, loculated effusion; L, liver; P, lung; S, spleen. *Rib shadows. Modified with permission from Via G, Storti E, Gulati G, Neri L, Mojoli F, Braschi A.[5]

the larynx and upper trachea via transcricothyroid probe placement can also confirm correct endotracheal tube positioning during and after placement.[16]

In patients with suspected pneumothorax, LUSA may not only provide a more timely and accurate assessment than chest radiography[17] but also permit real-time guidance at the moment of thoracostomy tube insertion. M-mode echocardiography can demonstrate the stratosphere or barcode sign, which represents reflection of the ultrasound beam from a static interface between the visceral and parietal pleura. The absence of sliding between visceral and parietal pleura suggests a pneumothorax. Another ultrasound finding that argues against pneumothorax is B lines, which in the presence of a pneumothorax would not be seen due to intrapleural air. Visualization of a pleural effusion and/or lung consolidation also allows pneumothorax to be ruled out, as even a thin layer of air beneath the parietal pleura would prevent imaging of pleural fluid or deeper tissue. In contrast, horizontal A lines without lung sliding are compatible with but do not rule in pneumothorax. The combination of A lines and the so-called lung point sign is confirmatory. The lung point sign is the ultrasound artifactual representation of a partially collapsed lung separating from the chest wall during expiration and recontacting the wall during inspiration. The lung point sign should be searched in an area more dependent than where the A-line (no-sliding) pattern was found.

Finally, LUSA can provide real-time feedback for the treatment of atelectasis as clinicians can visualize changes in lung aeration when positive end-expiratory pressure and recruitment maneuvers are used.[9]

EVIDENCE-BASED MEDICINE FOR THE APPLICATION OF INTRAOPERATIVE LUNG ULTRASONOGRAPHY

Lung ultrasound has emerged as a timely noninvasive bedside tool and demonstrated higher diagnostic accuracy compared to chest radiography and auscultation for many conditions. We have summarized in Table 3[3,6,11,16,17] the most current literature regarding patient-related conditions associated with hypoxemia and utilization of lung ultrasound for improved diagnostic accuracy. Much of this literature is summarized in the first International Consensus Conference on Lung Ultrasound.[13]

A 2013 meta-analysis found satisfactory diagnostic accuracy of LUSA for pneumothorax, with a pooled sensitivity of 78.6%–90.9% and specificity of 98.2%–98.4%.[17] In a 2012 study of 362 patients, LUSA also performed well in diagnosing pneumonia with a sensitivity of 93.4% and a specificity of 97.7%.[18]

Currently, the evidence for the intraoperative use of LUSA to diagnose hypoxemia is scarce. However, experience will accumulate with more widespread LUSA training for anesthesiology residents, greater implementation of LUSA curricula in anesthesiology residencies, increasing availability of ultrasound devices in the operating room, and heightened awareness of the intraoperative use of LUSA. A 2017 trial finding an ability of LUSA to track perioperative atelectasis,[14] for example, suggests such a role. Existing literature regarding the use of LUSA for diagnosing APE, pneumothorax, consolidation, and/or pleural effusion also supports a role for LUSA in the operating room.

RECOGNITION OF PITFALLS AND LIMITATIONS IN INTRAOPERATIVE ULTRASONOGRAPHY

LUSA images may not reflect a disease state with 100% certainty. For example, the presence of lung sliding in B mode and the sandy beach sign in M mode will have a nearly 100% negative predictive value for the diagnosis of a pneumothorax at that scanned level. However, the positive predictive value in the absence of those ultrasound reflections varies between 55% and 90%. Thus, the absence of lung sliding does not always imply the presence of a pneumothorax. Furthermore, pleural adhesions or large emphysematous bullae can present as a lack of pleural sliding in the absence of a pneumothorax.[19] In addition, a lung point sign may not be visible in a circumferential pneumothorax. Finally, access to the thorax during surgery may be limited by surgical drapes and the surgical procedure. However, sterile probe covers are available, which can facilitate LUSA evaluation of anatomic regions in proximity to the surgical field.

Table 3. Current Evidence of Lung Ultrasound Diagnostic Accuracy and Feasibility in Patient-Related Conditions Associated With Hypoxemia

Study	Clinical Condition/Setting	Diagnostic Accuracy	Comments
Ueda et al[2]	Initial intraoperative assessment of pneumothorax	Case reports: elective laparoscopic procedure/traumatic aortic dissection. Both cases of lung ultrasound provided timely diagnosis	Not mentioned CT as gold standard for diagnostic accuracy; lung ultrasound can be an important part of high-quality anesthesia care
Juang et al[11]	Intraoperative radiological assessment of pleural effusion	Two cases of massive pleural effusion that were only recognized after induction of anesthesia in living donor liver transplantation	Lack of utilization of lung ultrasound having higher diagnostic accuracy and availability in the operating room setting
Chou et al[16]	Detection of esophageal intubation. Twelve eligible studies involving adult patients and cadaveric models were identified from 1488 references	Ultrasonography had pooled sensitivity of 93% (95% CI, .86–.96) and a specificity of 97% (95% CI, 0.95–.98). The area under the summary ROC curve was 0.97 (95% CI, 0.95–.98)	Summary of evidence for high diagnostic value of ultrasonography for esophageal intubation
Alrajab et al[17]	Systematic review of 601 articles with the inclusion of 13 articles for a meta-analysis review. The aim is to evaluate the diagnostic accuracy of pleural ultrasonography in comparison with CXR for the diagnosis of pneumothorax	Lung US had a sensitivity of 78.6% (95% CI, 68.1–98.1) and a specificity of 98.4% (95% CI, 97.3–99.5). CXR had a pooled sensitivity of 39.8% (95% CI, 29.4–50.3) and a specificity of 99.3% (95% CI, 98.4–100.0)	Lung US is more accurate than CXR for detection of pneumothorax
Al Deeb et al[6]	Systematic review of 168 articles with the inclusion of 7 articles for a meta-analysis review. The aim is to determine the accuracy of US using B lines in diagnosing ACPE	The sensitivity of US using B lines to diagnose ACPE was 94.1% (95% CI, 81.3–98.3) and the specificity was 92.4% (95% CI, 84.2–96.4)	The results of this meta-analysis suggest that POC US using B lines may aid clinicians in the diagnosis of ACPE

Abbreviations: ACPE, acute cardiogenic pulmonary edema; CI, confidence interval; CT, computed tomography; CXR, chest x-ray; POC, point of care; ROC, receiver operating characteristic curve; US, ultrasound.

CONCLUSIONS

During the last decade, LUSA has progressively gained acceptance among anesthesia providers. Its clinical application has improved the diagnostic accuracy of potentially life-threatening conditions in the perioperative period. The noninvasive nature of this technique, lack of radiation, low cost, and easy access render this imaging approach reasonable for intraoperative and perioperative care. The use of LUSA for thoracic applications is now supported by clinical data and has been incorporated into best practice guidelines by medical specialties and consensus groups. LUSA is a contemporary skill that anesthesiologists should strongly consider incorporating into their clinical practice.

DISCLOSURES

Name: José L. Díaz-Gómez, MD.
Contribution: This author helped in study conception, study design, data collection, data analysis, data interpretation, and drafting and critically revising the article and figure or tables.
Name: J. Ross Renew, MD.
Contribution: This author helped in study conception, study design, data collection, data analysis, data interpretation, and drafting and critically revising the article and figure or tables.
Name: Robert A. Ratzlaff, DO.
Contribution: This author helped in study conception, study design, data collection, data analysis, data interpretation, and drafting and critically revising the article and figure or tables.
Name: Harish Ramakrishna, MD.
Contribution: This author helped draft and critically revise the article and figure or tables.
Name: Gabriele Via, MD.
Contribution: This author helped in study conception, study design, data collection, data analysis, data interpretation, and drafting and critically revising the article and figure or tables.
Name: Klaus Torp, MD.
Contribution: This author helped draft and critically revise the article and figure or tables.
This manuscript was handled by: Avery Tung, MD, FCCM.

REFERENCES

1. Kristensen MS, Teoh WH, Graumann O, Laursen CB. Ultrasonography for clinical decision-making and intervention in airway management: from the mouth to the lungs and pleurae. *Insights Imaging*. 2014;5:253–279.
2. Ueda K, Ahmed W, Ross AF. Intraoperative pneumothorax identified with transthoracic ultrasound. *Anesthesiology*. 2011;115:653–655.
3. Hiller KN, Hagberg CA. Intraoperative pulmonary ultrasound. *Anaesth Intensive Care*. 2014;42:141–142.
4. Mittal AK, Gupta N. Intraoperative lung ultrasound: a clinicodynamic perspective. *J Anaesthesiol Clin Pharmacol*. 2016;32:288–297.
5. Via G, Storti E, Gulati G, Neri L, Mojoli F, Braschi A. Lung ultrasound in the ICU: from diagnostic instrument to respiratory monitoring tool. *Minerva Anesthesiol*. 2012;78:1282–1296.
6. Al Deeb M, Barbic S, Featherstone R, Dankoff J, Barbic D. Point-of-care ultrasonography for the diagnosis of acute cardiogenic pulmonary edema in patients presenting with acute dyspnea: a systematic review and meta-analysis. *Acad Emerg Med*. 2014;21:843–852.
7. Dietrich CF, Mathis G, Blaivas M, et al. Lung B-line artefacts and their use. *J Thorac Dis*. 2016;8:1356–1365.
8. Caltabeloti F, Monsel A, Arbelot C, et al. Early fluid loading in acute respiratory distress syndrome with septic shock deteriorates lung aeration without impairing arterial oxygenation: a lung ultrasound observational study. *Crit Care*. 2014;18:R91.
9. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. *Am J Respir Crit Care Med*. 2011;183:341–347.
10. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology*. 2004;100:9–15.
11. Juang SE, Chen CL, Liao WT, et al. Two cases of massive pleural effusion noted only after induction of anesthesia in living donor liver transplantation. *J Anesth*. 2011;25:418–421.
12. Balik M, Plasil P, Waldauf P, et al. Ultrasound estimation of volume of pleural fluid in mechanically ventilated patients. *Intensive Care Med*. 2006;32:318.
13. Volpicelli G, Elbarbary M, Blaivas M, et al; International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med*. 2012;38:577–591.
14. Monastesse A, Girard F, Massicotte N, Chartrand-Lefebvre C, Girard M. Lung ultrasonography for the assessment of perioperative atelectasis: a pilot feasibility study. *Anesth Analg*. 2017;124:494–504.
15. Acosta CM, Maidana GA, Jacovitti D, et al. Accuracy of transthoracic lung ultrasound for diagnosing anesthesia-induced atelectasis in children. *Anesthesiology*. 2014;120:1370–1379.
16. Chou EH, Dickman E, Tsou PY, et al. Ultrasonography for confirmation of endotracheal tube placement: a systematic review and meta-analysis. *Resuscitation*. 2015;90:97–103.
17. Alrajab S, Youssef AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Crit Care*. 2013;17:R208.
18. Reissig A, Copetti R, Mathis G, et al. Lung ultrasound in the diagnosis and follow-up of community-acquired pneumonia: a prospective, multicenter, diagnostic accuracy study. *Chest*. 2012;142:965–972.
19. Tasci O, Hatipoglu ON, Cagli B, Ermis V. Sonography of the chest using linear-array versus sector transducers: correlation with auscultation, chest radiography, and computed tomography. *J Clin Ultrasound*. 2016;44:383–389.